

# Identified Particle Jet Correlations from PHENIX

Anne Sickles (for the PHENIX Collaboration ‡)

Brookhaven National Laboratory Upton, NY 11973

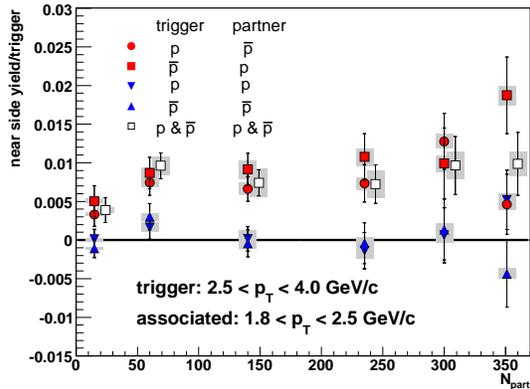
**Abstract.** Two-particle azimuthal correlations have been shown to be a powerful probe for extracting novel features of the interaction between hard scattered partons and the medium produced in Au+Au collisions at RHIC. At intermediate  $p_T$ , 2-5 GeV/c, jets have been shown to be significantly modified in both particle composition and angular distribution compared to p+p collisions. We present recent PHENIX results from Au+Au collisions for a variety of  $p_T$  and particle combinations.

One of the most surprising results from the Relativistic Heavy Ion Collider (RHIC) has been the large increase in the  $p/\pi^+$  and  $\bar{p}/\pi^-$  ratios at intermediate  $p_T$ , 2-5 GeV/c [1]. Studies of the yields of  $\Phi$  mesons [2] and  $\Lambda$  baryons [3] have indicated that the origin of the excess is related to the number of valence quarks rather than particle mass. Baryon and meson differences have also been studied by measuring the elliptic flow,  $v_2$ , of identified particles which have also been shown to scale with the number of valence quarks [4, 5, 6]. In this same  $p_T$  range in p+p collisions the dominant particle production mechanism shifts from soft, non-perturbative processes to hard parton-parton scattering followed by jet fragmentation [7]. The valence quark dependence of these effects has inspired a class of models based quark recombination; hadronization is modeled not by fragmentation, but by quarks close together in phase space coming together to form hadrons. In some of these models intermediate  $p_T$  hadrons primarily come from soft quarks [8]. In other models quarks from jet fragmentation are allowed to recombine with soft quarks [9]. All models in this class extend the range of soft particle production to higher  $p_T$  and start with thermalized quark degrees of freedom.

Two-particle correlations can be used to determine whether the baryon excess is associated with hard or soft processes and to explore in detail baryon/meson differences at low and intermediate  $p_T$ . A systematic study of these correlations will allow discrimination between different hadronization scenarios and measurement of the role of hard scattering at intermediate  $p_T$ . Here we present a selection of the recent PHENIX results from these correlations.

Correlations are measured between two classes of particles, *triggers* and *associated particles*. The data presented here are from the 2004 Au+Au  $\sqrt{s_{NN}}=200$  GeV RHIC run. Charged tracks are reconstructed in the drift chambers and particle identification is done via time of flight. The start time is from the Beam-Beam Counters and

‡ For the full list of PHENIX authors and acknowledgments, see Appendix Collaborations of this volume



**Figure 1.** Near side conditional yields per trigger for charge selected and charge inclusive  $p$  and  $\bar{p}$  correlations. Triggers have  $2.5 < p_T < 4.0$  GeV/ $c$  and associated particles have  $1.8 < p_T < 2.5$  GeV/ $c$ . Error bars are statistical errors and shaded boxes show systematic errors. There is an 11.4% (8.9%) additional normalization error on baryon ( $p, \bar{p}$ ) associated particle points. Figure is from Ref. [12].

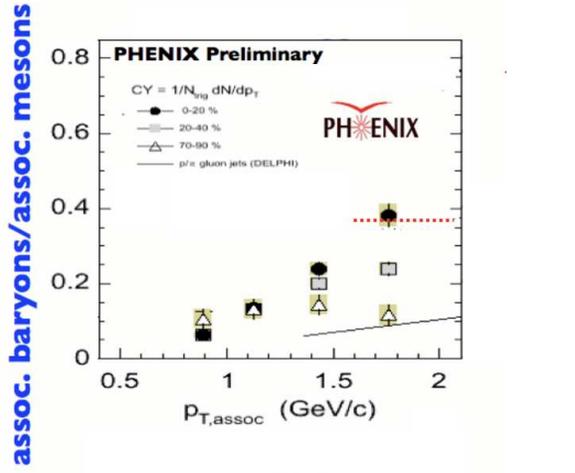
the stop time is measured by either the high resolution time of flight or the lead-scintillator electromagnetic calorimeter, which provide  $K/p$  separation to  $\approx 4.0$  GeV/ $c$  and  $\approx 2.5$  GeV/ $c$ , respectively. Azimuthal angular differences between trigger and associated particles,  $\Delta\phi$ , are calculated and the non-uniform  $\Delta\phi$  acceptance is corrected for with mixed pairs where the particles are from different events. Two methods are used to subtract combinatoric pairs from the underlying event. The first, the absolute subtraction method, uses a convolution of the single particle rates to determine the combinatoric pair rate. There is an additional correction for the width of the centrality bins used [10]. The second method, zero yield at minimum (ZYAM), makes the assumption that there is a region in  $\Delta\phi$  where there is the jet yield is zero [11]. Correlations from elliptic flow are removed by using  $v_2$  values measured independently in PHENIX [12]. The remaining yield is attributed jet correlations,  $J(\Delta\phi)$ . The  $\Delta\phi$  distributions are then described by:

$$\frac{1}{N_{trig}} \frac{dN}{d\Delta\phi} = B(1 + 2v_2^{trig}v_2^{assoc} \cos(2\Delta\phi)) + J(\Delta\phi) \quad (1)$$

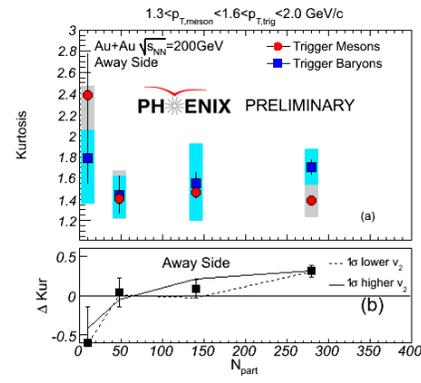
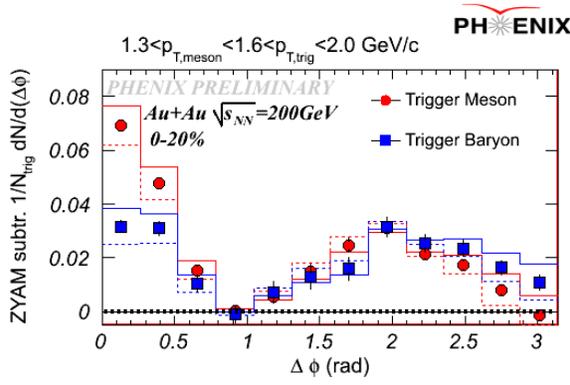
where  $B$  is the combinatoric background level and  $v_2^{trig}$  and  $v_2^{assoc}$  are  $v_2$  values for triggers and associated particles, respectively.  $N_{trig}$  is the total number of triggers.

Fig. 1 shows  $J(\Delta\phi)$  integrated for  $\Delta\phi < 0.94$  rad, i.e the yield of associated particles per trigger as a function of the number of participating nucleons,  $N_{part}$ . The  $\Delta\phi$  region covers where two correlated particles are expected to come from the fragmentation of the same jet. Both particles are identified as  $p$  or  $\bar{p}$  and different sets of points show the different charge combinations with triggers in the  $p_T$  region of the baryon excess. The baryon-baryon yield is flat with  $N_{part}$ , except for a smaller yield in the most peripheral collisions. Same sign pairs,  $p$ - $p$  and  $\bar{p}$ - $\bar{p}$  (triangles), show no yield and opposite sign pairs (filled circles and squares) are consistent with the charge independent yields. Yields are comparable for  $p$  and  $\bar{p}$  triggers.

Triggering on an intermediate  $p_T$  particle is expected to bias the near-side jet toward small medium path lengths. If so, the away-side,  $\Delta\phi \approx \pi$ , typically sees a long medium path length and could be a sensitive probe of medium modifications to the jet fragmentation process, hence we measure the particle composition of the



**Figure 2.** Ratio of associated baryons to associated mesons as a function of  $p_T$  for three centrality selections. Trigger particles are charged hadrons with  $2.5 < p_T < 4.0$  GeV/c. Dashed line shows the single particle baryon to meson ratio at  $p_T = 1.85$  GeV/c for central collisions calculated from Ref. [13].



**Figure 3.** (a)  $J(\Delta\phi)$  for baryon and meson triggers,  $1.6 < p_T < 2.0$  GeV/c, and associated mesons,  $1.3 < p_T < 1.6$  GeV/c. Background has been subtracted with the ZYAM assumption. (b) Top panel shows kurtosis as a function of  $N_{part}$  in the same  $p_T$  range as panel (a). Bottom panel shows the difference in the baryon and meson triggered kurtosis.

away-side jet. Fig. 2 shows the ratio of associated baryons to mesons ( $\pi^\pm, K^\pm$ ) with charged hadron triggers,  $2.5 < p_T < 4.0$  GeV/c, as a function of the associated particle  $p_T$  integrated over  $\Delta\phi$  from  $\pi$  to the minimum of  $J(\Delta\phi)$ . In peripheral collisions (triangles) the ratio of associated baryons to mesons on the away-side is approximately flat with  $p_T$ . In central collisions (circles) this ratio increases significantly with the associated particle  $p_T$ , suggesting that the away-side jet fragmentation is increasingly baryon rich at intermediate  $p_T$ . At the highest associated particle  $p_T$  shown in central collisions the ratio of associated baryons to mesons is consistent with the value observed in the single particles at the same  $p_T$  and centrality selections [13].

At intermediate  $p_T$  a modified away-side jet shape has also been observed [11]. In contrast to the Gaussian peak centered at  $\Delta\phi = \pi$  in p+p collisions, in central heavy ion collisions the shape is strongly non-Gaussian and the peak is displaced to

$\Delta\phi \approx 2\text{rad}$ . Parameters used to characterize the shape in hadron-hadron correlations appear to have a universal  $N_{part}$  dependence [14]. Identified particle correlations provide information on connections between away-side shape modifications and the baryon excess. Fig. 3(a) shows a  $\Delta\phi$  distribution for correlations of baryon and meson triggers,  $1.6 < p_T < 2.0 \text{ GeV}/c$ , with associated mesons,  $1.3 < p_T < 1.6 \text{ GeV}/c$ , in central collisions after the  $v_2$  and combinatoric background have been subtracted by the ZYAM procedure. These correlations are at lower  $p_T$  than in Ref. [14], but the displaced peak is at approximately the same position. Because of the low trigger  $p_T$  and the strong near-side differences in Fig. 3(a), further studies are needed to understand baryon/meson differences arising from the normal fragmentation process. The top panel of Fig. 3(b) shows the kurtosis of the away-side peak as a function of  $N_{part}$ . The systematic errors are dominated by the systematic errors on the  $v_2$  values used and are correlated between baryon and meson triggers.  $\Delta Kur = Kur_{bar} - Kur_{mes}$  is shown in the bottom panel and the lines show that in central collisions the kurtosis difference is insensitive to the uncertainties in  $v_2$ .

We have presented a variety of identified particle correlation results from PHENIX. Jet shape distributions at low  $p_T$  in central collisions are different for baryon and meson triggers. Mapping out the systematics of this effect, particularly the dependence on the associated particle type, will shed light into the origin of the modified away-side shape. Baryons have jet-like correlations in central collisions on both the near and away-side. The weak centrality dependence of the near-side yields in Fig. 1 is consistent with the excess baryons being produced in hard scattering processes. Other correlations in this  $p_T$  range are also consistent with this picture [12, 10]. However, two-particle correlations measure the average yield per trigger, but not the fraction of triggers which have associated particles. Away side particle ratios in central collisions are significantly more baryon rich than in peripheral collisions. Recombination models have not been able to systematically explain the two-particle correlation data. Further theoretical and experimental studies should allow a better understanding of the transition from hard to soft physics at intermediate  $p_T$  and the origin of the baryon excess.

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